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INTERACTIVE HYPERBOLIC GRID GENERATION FOR PROJECTILE CFD

EARL N. FERRY, JR.
CHARLES J. NIETUBICZ

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13. ABSTRACT (Maximum 200 words) The task of grid generation for projectile configurations has previously been performed using non-interactive batch codes. This is not necessarily a trivial task, and as configurations become more complicated, the grid generation process becomes more difficult. In an effort to make this task easier to perform, an existing, non-graphical grid generation code was ported from a VAX 8600 running VMS to an Iris Silicon Graphics work station running Irix. The new code, BRL-PROGRID (Projectile Grid generation), incorporated interactive graphics to provide ease and flexibility of use while at the same time allowing for many iterations of a grid to be generated. Capabilities gained through the development of the interactive grid generator are described. Examples of grids generated using a modified hyperbolic solver are shown for concave base cavities, and the application of CAD software to the grid generation process is discussed.				
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1. INTRODUCTION

The application of Computational Fluid Dynamics (CFD) to the field of Projectile Aerodynamics has seen continued progress. Early Navier-Stokes computational techniques have been used to predict pressure distributions on projectile configurations at transonic speeds (Nietubicz, Pulliam, and Steger 1980). Later studies (Nietubicz 1981; Nietubicz, Inger, and Danberg 1982; Sahu, Nietubicz, and Steger 1985) have provided predictions of aerodynamic coefficient data for conventional projectiles, hollow projectiles and projectiles with base bleed. Underlying the success of these Navier-Stokes solutions was the initial generation of a computational grid.

As part of any CFD numerical process, the region in which the equations of fluid motion are to be solved must be discretized into a finite set of node points. At each of these nodes, the laws of fluid motion are enforced with an appropriate solver, and a fluid dynamic solution can be obtained. The process of discretizing this flow-field region is known as *grid generation*.

Primary methods of grid generation are either algebraic or are based on solutions of partial differential systems of elliptic, parabolic, or hyperbolic equations. Work on projectile grid generation (Steger, Nietubicz, and Heavey 1981) included both algebraic and elliptic grid generation methods. The original code allowed for definition of projectile shapes, specification of body point clustering and choices of grid topology. This code was later enhanced to include the capability to generate hyperbolic grids (Nietubicz, Heavey, and Steger 1982). The primary advantage of the hyperbolic method is that it enforces conditions of orthogonality at each grid node and is a marching procedure as opposed to a more time-consuming elliptic method. Although this increases the speed and flexibility of the grid generator, the impact or need for this method was not fully appreciated until computational grids were required for the dome bases of the M864 and M825 projectiles (Nietubicz and Sahu 1988; Sahu, Nietubicz, and Heavey 1988). Up to this point, the grid generation process had always been performed in a non-interactive, batch mode environment.

The process of grid generation is not a trivial task even for relatively simple shapes. As body configurations become more complex, the task of creating a computational grid becomes

cumbersome and very time consuming. The grid generation process previously used for projectile aerodynamics at BRL made use of a combination of batch codes and static graphics displays which provided only limited analysis capabilities.

Through the introduction of powerful graphics work stations into the research and development workplace, visual analysis has become an important analytical tool for the engineer. This task has become easier to perform as the work stations have become faster in their compute and display speeds. Many of these work stations support zoom and pan capabilities which are also invaluable in the analysis process.

Presently there are several general purpose grid generation codes available within the United States which can handle a large number of very complex configurations. Many of these codes are well known, such as 3DGRAPE (Sorenson 1988, 1989), EAGLE (Thompson 1988; Thompson and Lijewski 1988), GRIDGEN (Steinbrenner, Chawner, and Fouts 1989), GENIE (Soni 1988), and VISUALGRID (Cordova 1990). These codes either exist already in an interactive mode, or are in the process of becoming interactive.

This report will describe the evolution of the BRL-PROGRID (Projectile Grid Generation) code to an interactive platform, and will discuss some of the new enhancements which have been added to the code for projectile grid generation. Additionally, the use of CAD software in providing initial body point distributions will be discussed. To date only the hyperbolic generator has been fully implemented and tested on both projectile and store separation configurations.

2. ORIGINAL BRL-PROGRID CODE

2.1 History. A projectile grid generation code originally developed by Joseph Steger (Steger 1979) was written in FORTRAN and ran on a VAX VMS system in a non-interactive mode. This code was later modified to include a hyperbolic solver, relaxation parameter, cell averaging, and secant nose configurations (Steger, Nietubicz, and Heavey 1981). An input data file was read and a data file containing the final grid was produced. Within the input file the user could select from an algebraic, elliptic, or hyperbolic solver to generate the grid. Also set within the input file were parameters such as the minimum normal spacing at the body,

CDS; spacing at the outer grid boundary, CDS2; the overall normal length of the grid, STOT; and the number of normal points in the grid, KMAX. If any of these parameters required modification, the user had to change the input file and re-run the code. Several other parameters are also set in the input file depending on whether the body is being input as discrete points or in a pseudo-analytical representation.

Next, a second program using DISSPLA software graphics calls was used to view the grid in order to determine if it was acceptable to be used by the appropriate solver. This process was very time consuming since the user could only view one part of the grid at a time. To complicate this task, the user also had to know the physical coordinates of the region which was to be viewed. If it was determined that the grid quality was not acceptable, the input data file had to be changed, and the process was repeated.

The additional requirement for grid point clustering in regions of interest presented another problem. If the user determined that it was necessary to cluster grid points around a region of rapidly changing geometry, these changes had to be made in the input data file and it became a trial and error iteration until the desired clustering was produced. This process was repeated for each zone of the grid until the entire configuration was complete.

Finally, a set of programs was used to create the grid in the region between the body and the base and then combine the grid zones into the correct format for different solvers. Different programs were used depending on grid zone location, desired final grid orientation, and the solver into which the grid would ultimately feed.

2.2 Hyperbolic Grid Generation Method. For most projectile applications, the outer boundary is unconstrained and simply needs to be placed far enough away from the projectile body so as not to adversely affect the flow field solution. This situation represents an ideal application for a hyperbolic grid generation scheme.

Once the body points have been adequately defined and the sting or cut has been determined, a grid can be generated using a hyperbolic solver similar to that described by Steger and Chaussee (1980). Before the actual solver can be implemented, however, the distance to the outer boundary must be specified and either constant spacing in η or some

type of stretching function is required. The η stretching used here is determined by the following relationship:

$$\Delta S_k = \Delta S_o (1 + \varepsilon)^{k-1}, \quad k = 1, k_{\max} - 1. \quad (1)$$

Here ΔS_o is the minimum specified grid spacing desired at the wall or inner boundary. The parameter ε is determined by a Newton-Raphson iteration process so that the sum of the above increments matches the known arc length between $\eta = 0$ and $\eta = \eta_{\max}$ for points which have the same value of ξ .

The governing equations for the hyperbolic solver are obtained by requiring (1) the coordinate lines ξ and η to be orthogonal and (2) the specification of a cell volume or area for the two dimensional case. The condition of orthogonality requires

$$\Delta \xi \cdot \Delta \eta = 0. \quad (2)$$

The second equation is obtained by specifying a grid cell volume (or area in two dimensions). Since the grid cell volume is finite, the transformation Jacobian will be greater than 1, i.e.,

$$dxdy = |x_\xi y_\eta - x_\eta y_\xi| d\xi d\eta. \quad (3)$$

The set of grid generation equations are, therefore, given in the physical plane by

$$\xi_x \eta_x + \xi_y \eta_y = 0$$

$$\xi_x \eta_y - \xi_y \eta_x = J$$

or in the transformed plane by

$$x_\xi x_\eta + y_\xi y_\eta = 0$$

$$x_\xi y_\eta - x_\eta y_\xi = 1/J \equiv V. \quad (4)$$

Using local linearization for this set of nonlinear differential equations, the resulting system

is shown to be hyperbolic and can, therefore, be marched in the η direction.

The linearized set of differential equations to be solved numerically is written in vector form as

$$A\vec{r}_\xi + B\vec{r}_\eta = \vec{f} \quad (5)$$

where

$$A = \begin{bmatrix} x_\eta^0 & y_\eta^0 \\ y_\eta^0 & -x_\eta^0 \end{bmatrix}, \quad B = \begin{bmatrix} x_\xi^0 & y_\xi^0 \\ -y_\xi^0 & x_\xi^0 \end{bmatrix}$$

$$\vec{f} = \begin{bmatrix} 0 \\ V + V^0 \end{bmatrix}, \quad \vec{r} = \begin{bmatrix} x \\ y \end{bmatrix}$$

and x_η^0, y_η^0 , etc., refer to known conditions.

The set of Equations (5) are solved with an implicit finite difference scheme which is first order accurate in the η direction (k) and where central differencing is used in the ξ direction (j). The resulting set of finite difference equations becomes

$$\frac{A(\vec{r}_{j+1,k+1} - \vec{r}_{j-1,k+1})}{2\Delta\xi} + \frac{B(\vec{r}_{j,k+1} - \vec{r}_{j,k})}{\Delta\eta} = \vec{f}_{j,k+1} \quad (6)$$

Rearranging Equation 6 and setting $\Delta\eta = \Delta\xi = 1$, results in

$$\frac{A}{2} \vec{r}_{j+1, k+1} + B \vec{r}_{j, k+1} - \frac{A}{2} \vec{r}_{j-1, k+1} = \vec{f}_{j, k+1} + B \vec{r}_{j, k} = \vec{d}_{j, k+1} \quad (7)$$

where

$$\vec{d}_{j, k+1} = \begin{bmatrix} (x_{\xi}^0 x^0 + y_{\xi}^0 y^0)_{j, k} \\ (-y_{\xi}^0 x^0 + x_{\xi}^0 y^0)_{j, k} + V + V^0 \end{bmatrix}.$$

Equation 7 is now in a form which can be easily solved by inverting a block tridiagonal matrix with 2×2 blocks. The terms x_{ξ}^0 and y_{ξ}^0 are central differenced as

$$\begin{aligned} x_{\xi, j, k}^0 &= \frac{x_{j+1, k} - x_{j-1, k}}{2} \\ y_{\xi, j, k}^0 &= \frac{y_{j+1, k} - y_{j-1, k}}{2}. \end{aligned} \quad (8)$$

The terms x_{η}^0 and y_{η}^0 are obtained from Equation 4 evaluated at the old station (o). That is,

$$\begin{aligned} x_{\xi}^0 x_{\eta}^0 + y_{\xi}^0 y_{\eta}^0 &= 0 \\ x_{\xi}^0 y_{\eta}^0 - x_{\eta}^0 y_{\xi}^0 &= V^0. \end{aligned} \quad (9)$$

Solving for x_{η}^0 and y_{η}^0 with x_{ξ}^0 and y_{ξ}^0 given in Equation 8 yields

$$x_{\eta}^0 = \frac{-y_{\xi}^0 V^0}{(x_{\xi}^{0^2} + y_{\xi}^{0^2})} \quad y_{\eta}^0 = \frac{x_{\xi}^0 V^0}{(x_{\xi}^{0^2} + y_{\xi}^{0^2})}. \quad (10)$$

Now the cell volume remains to be specified. This specification is important since it has the effect of controlling the grid evolution as the solution is being marched out from the body. The method chosen here is straightforward and uses the stretching function given by Equation 1. Specifying the minimum spacing at the wall Δs_0 and the total number of points j_{max} in the η direction, an array of arc lengths Δs_k is determined. Since the Δx is known along the j line, the volumes are calculated by

$$V = (\Delta s_k) (x_{j+1,k} - x_{j,k}) . \quad (11)$$

This specification of cell volumes yields smoothly varying grids in the η direction. Grid volume control is obtained by varying the arc length distribution Δs_k and/or surface point distribution. A grid generated using this technique is shown in Figure 1. Figures 2 and 3 expand the base region and show the grid generated for the concave base cavity of the M864 projectile. An additional volume specification approach can be found in Steger and Chaussee (1980).

Due to the concavity of the base region on the M864 projectile shown in Figure 3, the use of a hyperbolic solver would normally lead to a grid which was unacceptable for use in a CFD code solver. The grid would be unacceptable because enforcing conditions of orthogonality in this region would lead to grid cells crossing and overlapping each other. A more general form of the hyperbolic equation set was developed by Kinsey and Barth (July 1984) which enables grids to be generated for complex configurations such as the base region of the M864 projectile. The generalization is obtained by replacing the backward integration in η of equation 6 with

$$\frac{B(\vec{r}_{j,k+1} - \vec{r}_{j,k})}{\Delta \eta} = (1 - \alpha)(\vec{r}_\eta)_k + \alpha(\vec{r}_\eta)_{k+1} \quad (12)$$

where α is used to control the type of finite difference marching algorithm and has the resultant effect of relaxing the degree of orthogonality of the grid. When $\alpha = 1$, the original scheme is maintained and the grid is everywhere orthogonal. For $\alpha > 1$ the numerical error term is dissipative and the grid is no longer fully orthogonal.

The final grid generated using the generalized equations is shown in Figure 3 and required ALPHA set at 6. The effect of lowering the value of ALPHA to 3 is shown in Figure 4. Any further attempt to reduce the value of ALPHA leads to grid line crossing for this configuration.

An additional change was made in the code to reduce the propagation of body discontinuities into the grid as the grid is marched toward the outer boundary. This is accomplished through a smoothing parameter, ITERV, which is used to average the grid cell volumes of Equation 11. ITERV is the number of averaging sweeps taken for the specified volume, V_j . An ITERV value of 36 was required to generate a smooth grid with only minor propagation of the concave region of the base surface toward the outer boundary of the grid (see Figure 2). Setting ITERV equal to 0 disables this averaging procedure and generates the grid shown in Figure 5. Here, the effect of the base cavity is seen to propagate toward the down stream boundary.

3. INTERACTIVE BRL-PROGRID CODE

3.1 Body Definition. One of the first difficulties encountered in trying to develop a finite difference grid is that of attempting to get an accurate definition of the body surface. In an effort to solve this problem, it was decided that a CAD/CAM program could be used in conjunction with the engineering drawings to produce an accurate representation of the configuration of interest. A PC program called CADKEY was chosen since it was easy to use and provided output files in a format which could easily be used to create a discrete set of body points.

Engineering drawings are rapidly and easily entered into the CADKEY program via a combination of mouse and/or keyboard input. An example of a drawing created using CADKEY is shown in Figure 6. Once the design is inside CADKEY it can be written out in a variety of different formats. One of these formats is a ".CDL" file. This file contains the analog information defining each of the curves which make up the projectile's surface. A sample ".CDL" file for the M864 projectile configuration is shown in Figure 7. A FORTRAN program is then run which takes the information contained in the ".CDL" output file and calculates a set of discrete points to define the projectile surface. The data file containing these points is then used as part of the input file to the interactive grid generator.

3.2 Grid Generation. The process of continually entering and exiting several different programs in order to make even relatively simple changes to the generated grid was very time consuming and inefficient. In order to speed up this necessary and important process, interactive graphics were incorporated into the grid solver. The developed graphical interface makes use of the Silicon Graphics GL Library and the geometry engines of the Iris 4D series work stations to provide more rapid computation and analysis of a hyperbolic grid.

Incorporated into the interactive grid generator was the ability to zoom and pan the final grid. This allows the user to rapidly view a region of the grid which might be suspected of having discontinuities. The user can also separately control the sensitivity of the mouse for zooming and panning. Color was also added to facilitate the analysis of zonal grids. The grid shown in Figure 1 consists of three zones when it is originally generated: the body grid, shown in red; the base grid, shown in yellow; and the "fill" grid, shown in blue. Without the use of color, the process of checking for correct grid overlap and/or meshing would be a very difficult task. Another feature which was added was the ability to interactively redistribute points along the body surface. This gives the user unlimited flexibility to add, subtract, or recluster the points defining the projectile surface and immediately regenerate a new grid. Also added was the ability to interactively change the parameters CDS, CDS2, STOT, ALPHA, ITERV, and KMAX which provide conditions or constraints for the formulation of the grid. Once any or all of these parameters have been changed, the user can immediately regenerate the grid and view it to see if the changes brought about the desired results. The user can also create the grid region between the body and the base with one keystroke once the body and base grids have been created and saved. These new abilities provide a more efficient method of creating and analyzing a computational grid. Every part of the generation process is handled by one program, rather than using several programs as was previously required. This makes it easier for the user to more rapidly create a finite difference grid.

The opening screen for BRL-PROGRID is shown in Figure 8. The Main Menu options currently available are: Input Body File, Input Base File, Re-Distribute Points, Change Parameters, Form Grid, Un-Do a Regrid, Show Body Only, Show Base Only, Show Body and Base, Save Grid, Exit Menu, and Exit Program. A more detailed discussion of these menu options and a sample session are presented in Appendix A which also serves as a Users' Guide for the program.

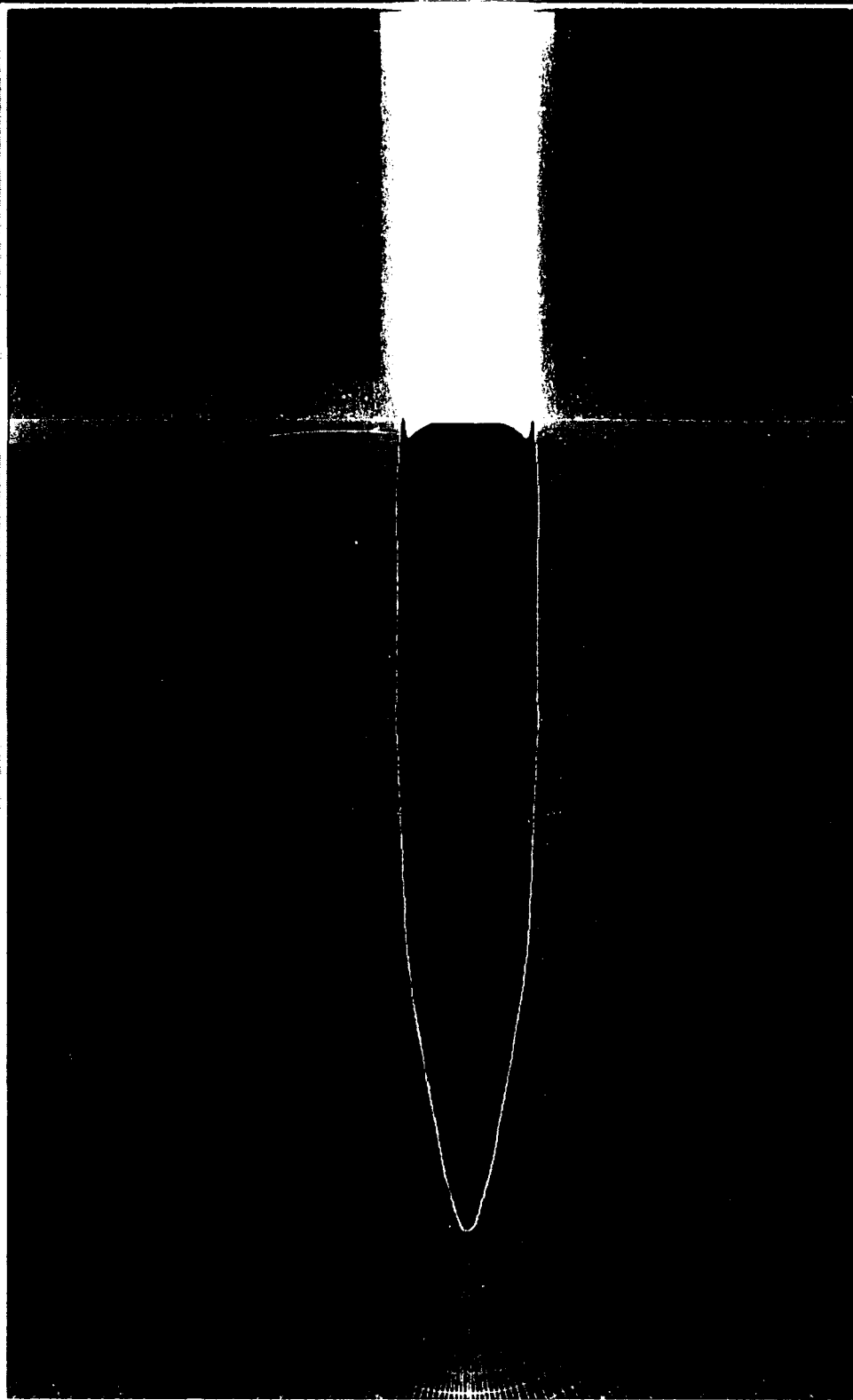
4. GRID POST-PROCESSING

Once the user has created and saved all the desired grid zones, BRL-PROGRID is closed and BRL-GRIDCOMB is run. BRL-GRIDCOMB is written in FORTRAN on an Iris 4D work station, and uses the Iris GL Library and geometry engines for controlling the graphics. This program takes as input, multiple PLOT3D (Walatka and Buning 1989) format, 2D, single grids and allows the user to interactively combine all the grids into the correct format and orientation for either the F3D code (Sahu 1988), or the AXISYMMETRIC Navier-Stokes codes (Nietubicz, Pulliam, and Steger 1980). It also allows the user to interactively split up a large grid into smaller grids for input into the zonal F3D code. When the user is done, the code writes out the final grid(s) in the desired format. BRL-GRIDCOMB also allows the user to zoom and pan across the grid(s).

5. SUMMARY

An interactive hyperbolic projectile grid generation capability has been developed for use on the Iris Silicon Graphics workstations. The addition of user interaction through graphics has made the hyperbolic grid generation task easier and faster to complete. An existing batch code was ported to the Iris Silicon Graphics 4D/xxx series of work stations in order to facilitate the incorporation of interactive graphical analysis capabilities into the grid generation process. Capabilities gained from this port include zoom/pan ability, body surface point redistribution, and spacing control in the normal direction. All of these tasks can now be completed without the user being required to exit the program, make changes in the input file, and enter the program again with the changed input file.

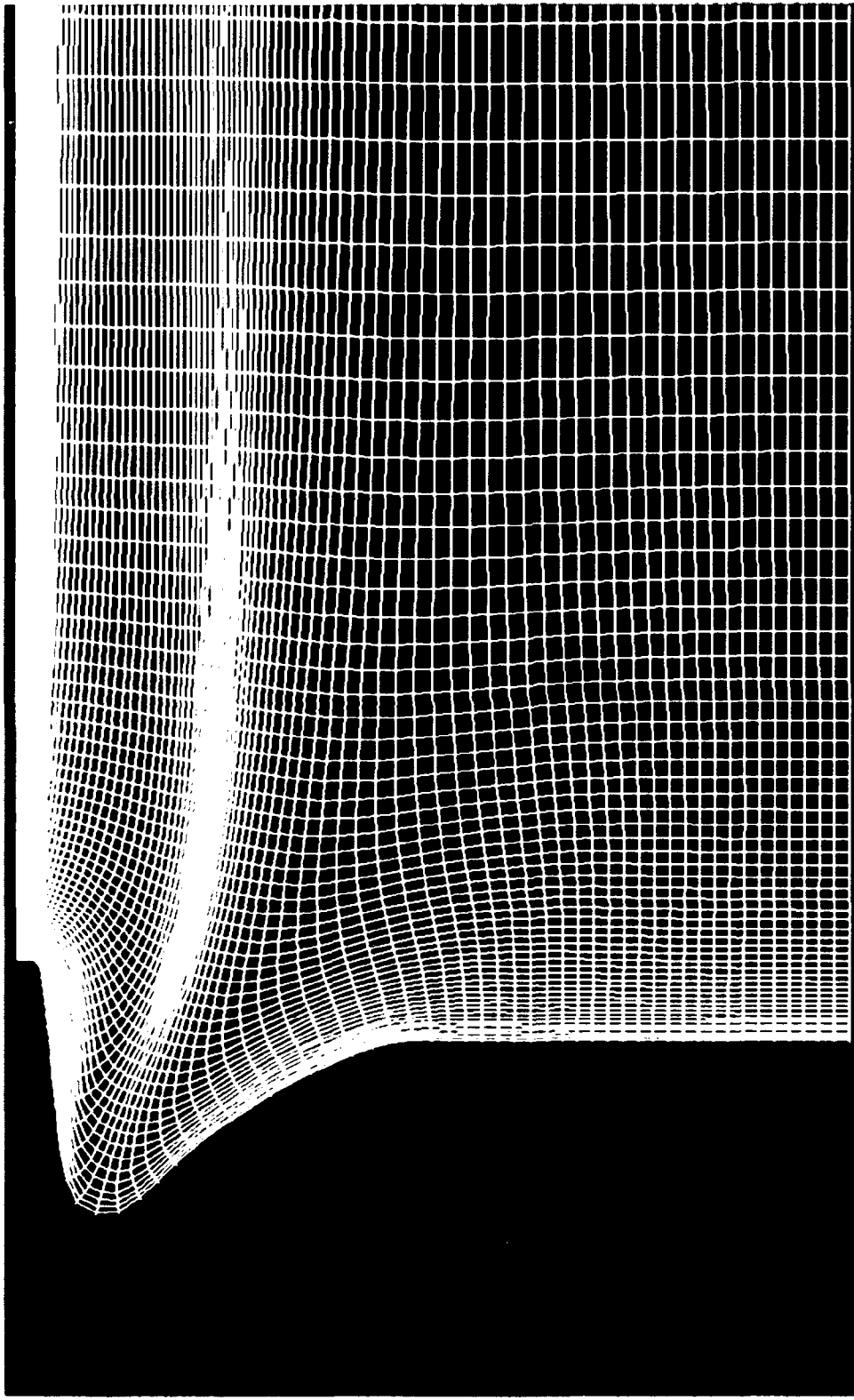
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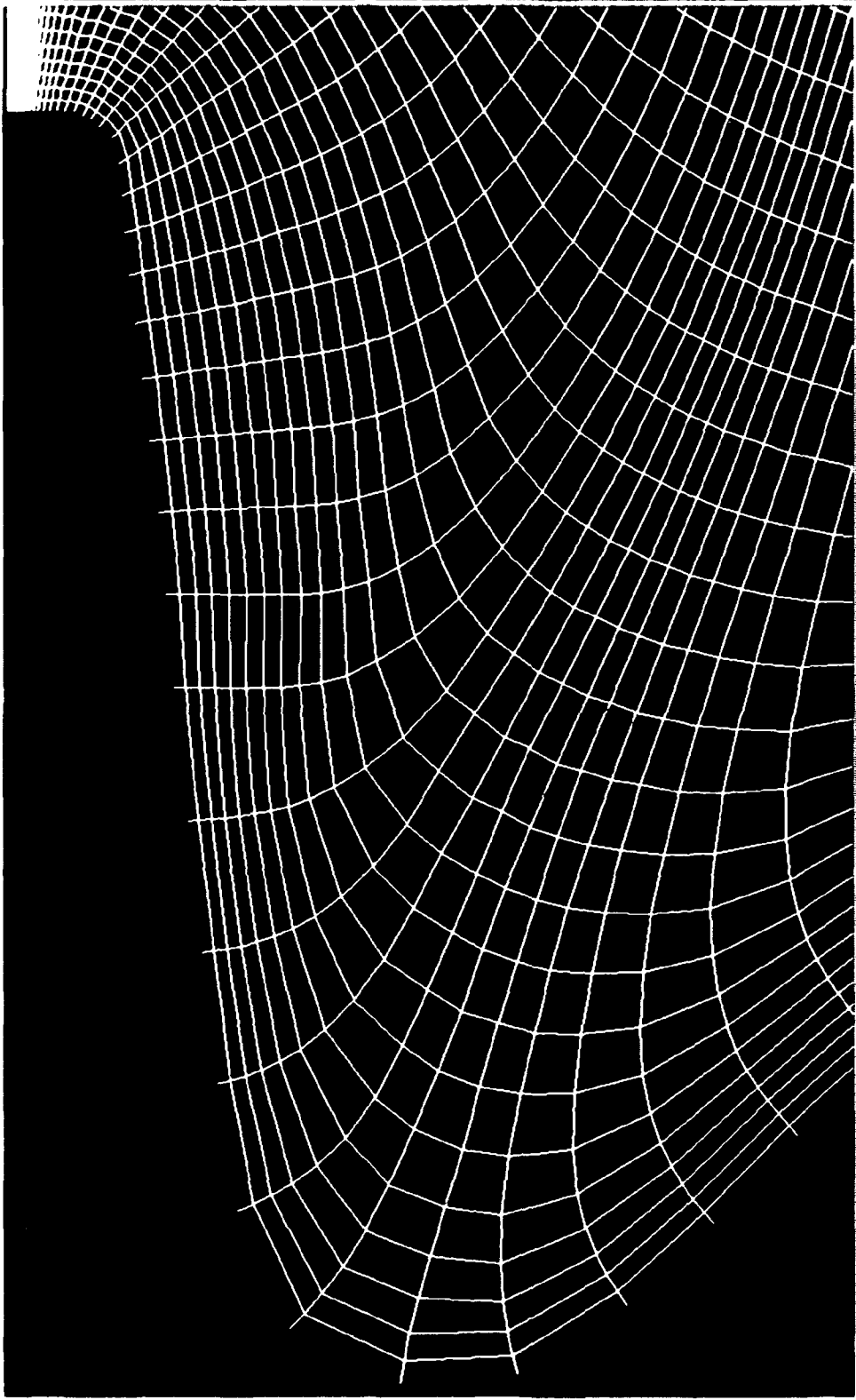
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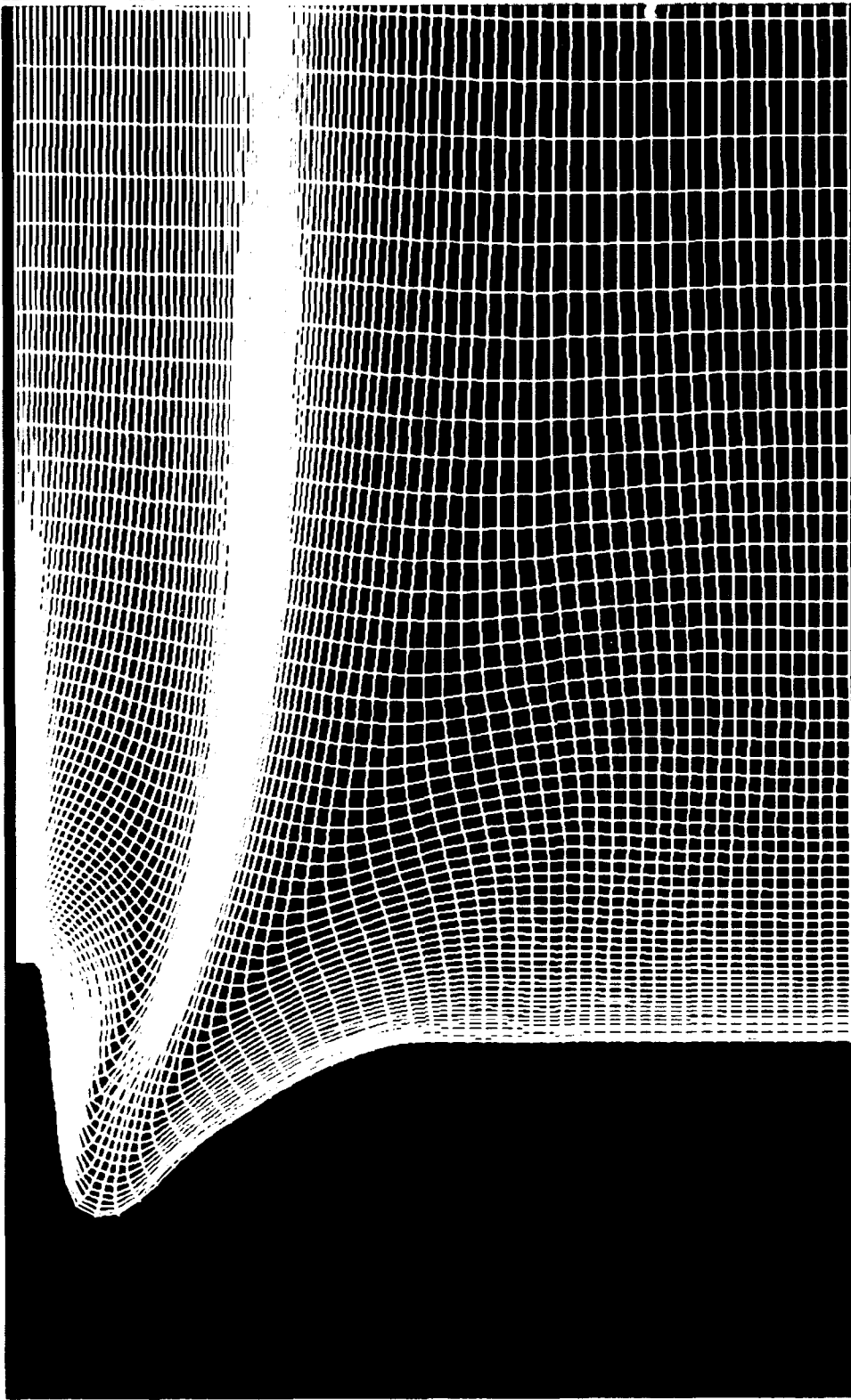
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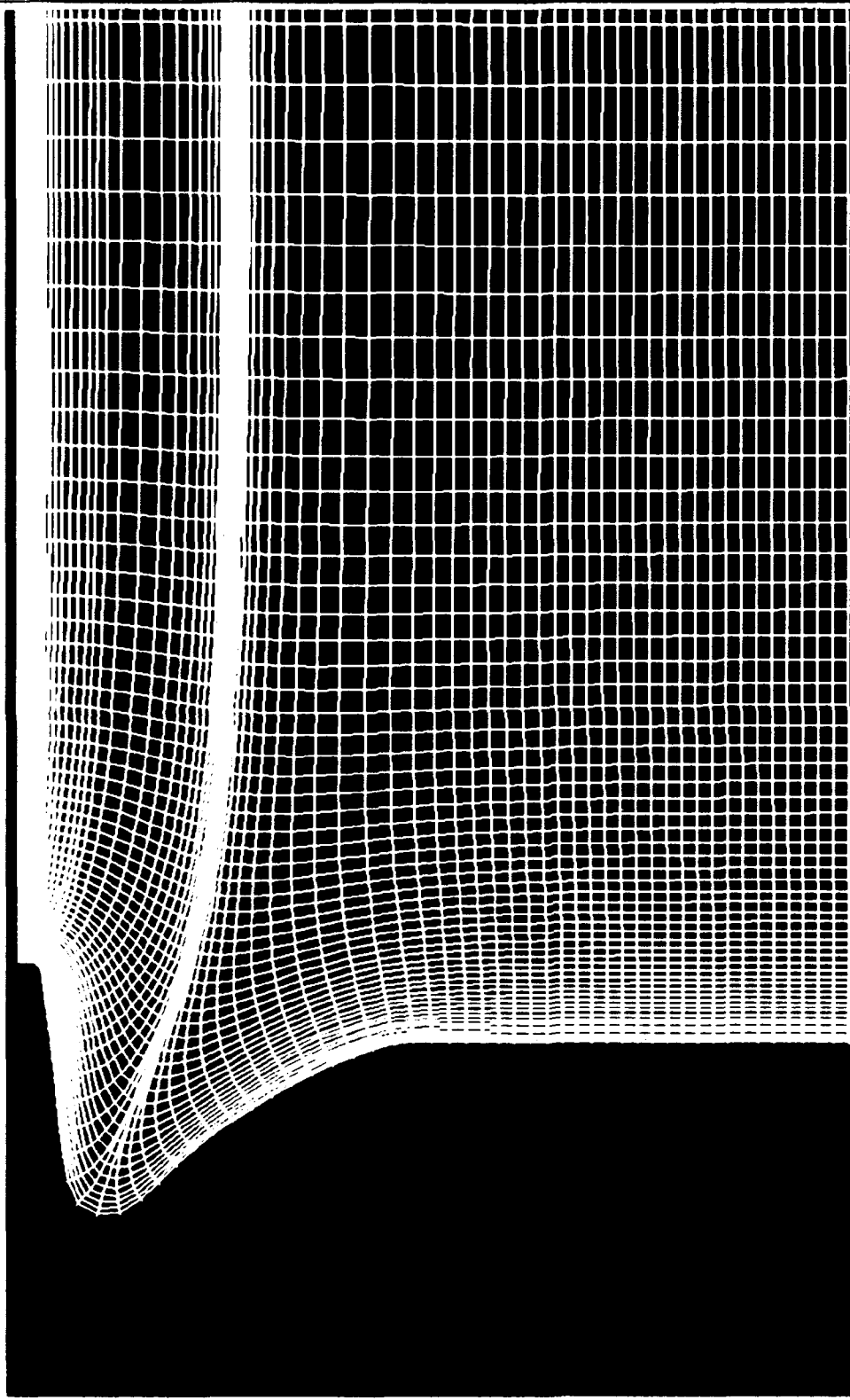


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HRL - PHOTOGRAPH



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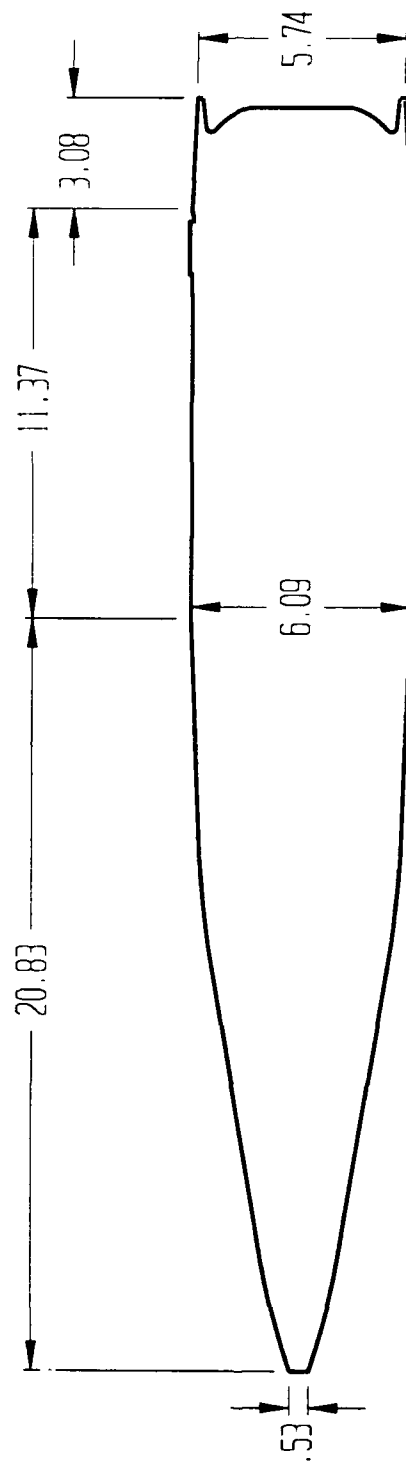


Figure 6. CADKEY Drawing of M864 Projectile.

```

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LINE 23.0100000000, -3.0251160000, 0.0000000000, 23.1000000000, -3.0051160000, 0.0000000000, 1, 1, 1, 4, 1, 1, 1
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Figure 7. CADKEY ".CDL" File for M864 Projectile.

Input BODY File

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1000

Year	Number of cases	Rate per 100,000
1990	1,000	1.0
1991	1,100	1.1
1992	1,200	1.2
1993	1,300	1.3
1994	1,400	1.4
1995	1,500	1.5
1996	1,600	1.6
1997	1,700	1.7
1998	1,800	1.8
1999	1,900	1.9
2000	2,000	2.0
2001	2,100	2.1
2002	2,200	2.2
2003	2,300	2.3
2004	2,400	2.4
2005	2,500	2.5
2006	2,600	2.6
2007	2,700	2.7
2008	2,800	2.8
2009	2,900	2.9
2010	3,000	3.0
2011	3,100	3.1
2012	3,200	3.2
2013	3,300	3.3
2014	3,400	3.4
2015	3,500	3.5
2016	3,600	3.6
2017	3,700	3.7
2018	3,800	3.8
2019	3,900	3.9
2020	4,000	4.0

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1. *Journal of the American Medical Association*, 1997; 277: 1039-1043.

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Figure 1

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www.hindawi.com

[illegible]

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Figure 1. The effect of the concentration of the solution on the adsorption of the dye. The concentration of the solution was 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 15.0, 20.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0, 100.0, 150.0, 200.0, 300.0, 400.0, 500.0, 600.0, 700.0, 800.0, 900.0, 1000.0, 1500.0, 2000.0, 3000.0, 4000.0, 5000.0, 6000.0, 7000.0, 8000.0, 9000.0, 10000.0, 15000.0, 20000.0, 30000.0, 40000.0, 50000.0, 60000.0, 70000.0, 80000.0, 90000.0, 100000.0, 150000.0, 200000.0, 300000.0, 400000.0, 500000.0, 600000.0, 700000.0, 800000.0, 900000.0, 1000000.0, 1500000.0, 2000000.0, 3000000.0, 4000000.0, 5000000.0, 6000000.0, 7000000.0, 8000000.0, 9000000.0, 10000000.0, 15000000.0, 20000000.0, 30000000.0, 40000000.0, 50000000.0, 60000000.0, 70000000.0, 80000000.0, 90000000.0, 100000000.0, 150000000.0, 200000000.0, 300000000.0, 400000000.0, 500000000.0, 600000000.0, 700000000.0, 800000000.0, 900000000.0, 1000000000.0, 1500000000.0, 2000000000.0, 3000000000.0, 4000000000.0, 5000000000.0, 6000000000.0, 7000000000.0, 8000000000.0, 9000000000.0, 10000000000.0, 15000000000.0, 20000000000.0, 30000000000.0, 40000000000.0, 50000000000.0, 60000000000.0, 70000000000.0, 80000000000.0, 90000000000.0, 100000000000.0, 150000000000.0, 200000000000.0, 300000000000.0, 400000000000.0, 500000000000.0, 600000000000.0, 700000000000.0, 800000000000.0, 900000000000.0, 1000000000000.0, 1500000000000.0, 2000000000000.0, 3000000000000.0, 4000000000000.0, 5000000000000.0, 6000000000000.0, 7000000000000.0, 8000000000000.0, 9000000000000.0, 10000000000000.0, 15000000000000.0, 20000000000000.0, 30000000000000.0, 40000000000000.0, 50000000000000.0, 60000000000000.0, 70000000000000.0, 80000000000000.0, 90000000000000.0, 100000000000000.0, 150000000000000.0, 200000000000000.0, 300000000000000.0, 400000000000000.0, 500000000000000.0, 600000000000000.0, 700000000000000.0, 800000000000000.0, 900000000000000.0, 1000000000000000.0, 1500000000000000.0, 2000000000000000.0, 3000000000000000.0, 4000000000000000.0, 5000000000000000.0, 6000000000000000.0, 7000000000000000.0, 8000000000000000.0, 9000000000000000.0, 10000000000000000.0, 15000000000000000.0, 20000000000000000.0, 30000000000000000.0, 40000000000000000.0, 50000000000000000.0, 60000000000000000.0, 70000000000000000.0, 80000000000000000.0, 90000000000000000.0, 100000000000000000.0, 150000000000000000.0, 200000000000000000.0, 300000000000000000.0, 400000000000000000.0, 500000000000000000.0, 600000000000000000.0, 700000000000000000.0, 800000000000000000.0, 900000000000000000.0, 1000000000000000000.0, 1500000000000000000.0, 2000000000000000000.0, 3000000000000000000.0, 4000000000000000000.0, 5000000000000000000.0, 6000000000000000000.0, 7000000000000000000.0, 8000000000000000000.0, 9000000000000000000.0, 10000000000000000000.0, 15000000000000000000.0, 20000000000000000000.0, 30000000000000000000.0, 40000000000000000000.0, 50000000000000000000.0, 60000000000000000000.0, 70000000000000000000.0, 80000000000000000000.0, 90000000000000000000.0, 100000000000000000000.0, 150000000000000000000.0, 200000000000000000000.0, 300000000000000000000.0, 400000000000000000000.0, 500000000000000000000.0, 600000000000000000000.0, 700000000000000000000.0, 800000000000000000000.0, 900000000000000000000.0, 1000000000000000000000.0, 1500000000000000000000.0, 2000000000000000000000.0, 3000000000000000000000.0, 4000000000000000000000.0, 5000000000000000000000.0, 6000000000000000000000.0, 7000000000000000000000.0, 8000000000000000000000.0, 9000000000000000000000.0, 10000000000000000000000.0, 15000000000000000000000.0, 20000000000000000000000.0, 30000000000000000000000.0, 40000000000000000000000.0, 50000000000000000000000.0, 60000000000000000000000.0, 70000000000000000000000.0, 80000000000000000000000.0, 90000000000000000000000.0, 100000000000000000000000.0, 150000000000000000000000.0, 200000000000000000000000.0, 300000000000000000000000.0, 400000000000000000000000.0, 500000000000000000000000.0, 600000000000000000000000.0, 700000000000000000000000.0, 800000000000000000000000.0, 900000000000000000000000.0, 10000000

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Abstract

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466
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APPENDIX:

**BRL-PROGRID USER'S GUIDE FOR
INTERACTIVE HYPERBOLIC GRID GENERATION PROGRAM**

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INTRODUCTION

- 1) Type "progrid" at the command prompt.
- 2) The Main Menu will appear in the upper right corner, click the right mouse button on "input body file."
- 3) Control will move to the textport at the bottom of the screen where you can type in the name of your input file. (The structure of the input file is outlined later in the Input File Format section.)
- 4) If the data file is read in correctly, the body and grid will appear in the viewport.
- 5) Use the right mouse button to translate the grid, the middle mouse button to zoom the grid, and the left mouse button to reset the translation and zooming to default.
- 6) If the computed grid is unsatisfactory, press the "m" key to activate the Main Menu and perform one of the following options:
 - a) Click the right mouse button on the "Change Parameters" option. Control will transfer to the textport. The parameters you can change are:
 - cds - spacing at body (-1 for constant distance)
 - cds2 - spacing at outer body
 - stot - total distance to outer boundary
 - alpha - smoothing parameter to "relax" grid orthogonality conditions
 - iterv - number of grid smoothing iterations
 - kmax - number of grid points in the normal direction.
 - b) Click the right mouse button on the "Re-Distribute Points" option. Refer to the sample point redistribution session later in this text for more information.
- 7) Return control to the Main Menu and click on the "Form Grid" option to compute a new grid using the new parameters or new point distribution.
- 8) If the grid is satisfactory, turn on the Main Menu (MKey) and click on the "Save Grid" option. Control will pass to the textport where you should enter a 1 to save your new body grid.
- 9) The grid is created in two dimensions, however, you can save the grid in either ASCII or "unformatted" PLOT3D - 2D or 3D format. Also, at this point, the grid can be rotated into a 3D solid; first enter the total number of degrees of rotation, then the number of planes desired. The rotated output file can be saved in X-Y-Z columnar format, and/or PLOT3D format.

10) Click on "Exit Program" and confirm in the textport to exit.

BRL-PROGRID INPUT BODY FILES and DATA FILE STRUCTURE

1) The input file structure of the BRL-PROGRID program has been changed so as to keep compatibility with the VAX batch code BRL grid generator.

BRL-PROGRID input file structure:

<u>variable or flag name</u>	<u>data type</u>
isolv, i3d, ibase, nd, lmax, alpha, iterv	
jmax, kmax, ibc, idat, iscal, iclus, stot, cds, cds2	
xx(i) yy(i)	

Here, isolv, i3d, ibase, nd, lmax, alpha, iterv, jmax, kmax, ibc, idat, iscal, and iclus are integers; and stot, cds, cds2, xx(i), and yy(i) are reals.

These inputs have the following meanings:

isolv - 0 for elliptic solver (currently an unsupported feature)
- 1 for hyperbolic solver (always use integer 1)

i3d - 0 for 2D grid (no spin) - most commonly used setting
- 1 for 3D grid (half plane spin)
- 2 for 3D grid (full plane spin)

ibase - 0 for no base grid (most used option)
- 1 for exponential clustering in base region
- 2 for Vinokur's clustering in base region

nd - number of circumferential planes (usually zero)

lmax - number of circumferential planes (same as nd)

alpha - smoothing parameter to "relax" orthogonality conditions

iterv - number of grid smoothing iterations

jmax - number of longitudinal planes

kmax - number of normal planes

ibc - 0 for boundary conditions along negative x-axis at J=1
- 1 for B.C.'s perpendicular to x-axis at J=1
- 2 for boundary conditions along positive x-axis at J=1

- idat - 0 for body points created analytically within program (rarely used setting)
 - 1 for body points read in from input file (unit 5) - most commonly used setting
 - 2 for body points read in from separate input file (unit 7)
- iscal - 0 for no rescaling of hyperbolic grid
 - 1 for rescaling of hyperbolic grid
- iclus - 0 for original clustering in normal direction
 - 1 for Vinokur's clustering in normal direction
- stot - total distance to outer boundary (-1 for constant spacing using $(kmax * cds)$ to
 determine the final distance to the outer boundary)
- cds - spacing at body
- cds2 - spacing at outer boundary
- xx(i) - X position of body surface points ($j = 1$ to $jmax$)
- yy(i) - Y position of body surface points ($j = 1$ to $jmax$)
 (Note: all read statements are free formatted.)

BRL-PROGRID MAIN MENU PANEL

Input Body File: Used to input a body shape from an existing file. The user can type "quit" here to quit the program.

Input Base File: Used to input a base shape from an existing file. (A base is a body rotated 90 degrees.) The user can type "quit" here to quit the program.

Re-Distribute Points: Used to change the point distribution of the body or base file. (An example of how to use this option follows this section.)

Change Parameters: Changes the input parameters: cds, cds2, stot, alpha, iterv, and kmax.

Form Grid: Forms new grid after changing an input parameter, or redistributing the body or base points.

Un-Do a Regrid: Un-Does a regrid.

Show Body Only: Displays only the BODY (red grid in Figure 1) for manipulation if both a body and base grid have been created.

Show Base Only: Displays only the BASE (yellow grid in Figure 1) for manipulation if both a body and base grid have been created.

Show Body and Base: Show both the BODY and BASE if a body and base grid have been created.

Note: If you select this option, it is only possible to zoom and translate the grid. Parameter changes and point re-distribution are not possible.

Save Grid: Saves the grid as a PLOT3D format, 2D or 3D, ASCII or unformatted data file. Also contains an option for 3D grid rotation.

Exit Menu: Turns the Main Menu off, and sends mouse control to the viewscreen. (The Main Menu must be turned off to zoom and translate.)

Exit Program: Clears the textport and exits the program if you confirm your selection in the textport.

MOUSE BUTTON FUNCTIONS

Left Mouse Button: Reset zoom and translate to default.

Right Mouse Button: Translate object.

Middle Mouse Button: Zoom object.

BRL-PROGRID KEYBOARD MACROS

(These keys are activated when the Main Menu is turned off.)

Escape key: Exits program.

B key: Turns the viewport background color black (default).

C key: Displays the current X and Y translations and current zoom factor in the textport.

F Key: Creates a "fill grid" (blue grid in Figure 1) between a body grid and base grid.

H key: (Help Key) Draws a picture of the mouse, telling how to zoom, translate and reset transformations.

L key: Gives the current X and Y translations and zoom factors, and asks for new values. This option will allow keyboard or data file entry of translation and zooming factors without using the mouse. If you do not wish to change a value, hit return, and the old value will remain, if you do change a value, make sure you enter it as a real number (include decimal point). For data file input, the user is prompted for an input file name. The format for this file is: x-translation, y-translation, zoom factor in free-format.

M key: Turns the Main Menu panel on.

Note: Menu panel must be turned off in order to zoom and translate the grid.

P Key: Position set/toggle. Using this key, the user can set two viewing locations and toggle between them. The user is prompted for input as to whether they are setting a toggle position or are toggling between two positions which are already set.

R key: Toggles grid reflection on and off.

S key: Save a zoom/translation data file.

W key: Turns the viewport background color white.

(up arrow): Increase zoom sensitivity.

(down arrow): Decrease zoom sensitivity.

(right arrow): Increase translate sensitivity.

(left arrow): Decrease translate sensitivity.

Example of Point Redistribution Menu Option:

1) Click the right mouse button on the "Re-distribute Points" option in the Main Menu after reading in a body or base file.

2) Click the left or right mouse buttons to move along the body's points. Move to the first desired point and click the middle mouse button. The selected point will turn yellow to indicate that it has been selected as an endpoint. Now move to the next desired point and click the middle mouse button to select this point as your second endpoint.

Note: You can only select two (2) endpoints to re-distribute between. To un-select an endpoint, move to that point and click the middle mouse button. The point will no longer be displayed in yellow, and you can now select a new endpoint.

3) Hit the R-Key to redistribute points between the chosen endpoints. You will be prompted for input as to how many points you would like to have between the chosen endpoints.

4) You will now be asked if you want linear or Vinokur's clustering in the X-direction. If you choose Vinokur's, you will have to input "dy0" and "dy1", which are user specified endpoint spacings at the left and right endpoints respectively.

5) If this new point distribution is satisfactory, type the K-Key to keep the new points, and hit the Escape-Key to go back to the Main Menu. Click on "Form Grid" to compute the new grid. If you wish to un-do the redistribution, hit the U-Key and either, re-do the redistribution or press the Escape-Key to go back to the Main Menu.

Re-Distribute Points; key functionality:

Left Mouse: Decreases the point number index.

Right Mouse: Increases the point number index.

Middle Mouse: Selects/Unselects the current point as an endpoint.

K-Key: Keep the point redistribution.

R-Key: Redistribute the points.

S-Key: Show currently selected redistribution end points.

U-Key: Undo the point redistribution.

up-arrow: Places the user in "fast scroll" mode for left and right mouse buttons. In this mode, the user can "press-and-hold" a mouse button for rapid increase or decrease of point number index.

down-arrow: Places the user in "slow scroll" mode for left and right mouse buttons. In this mode, the user must press-and-release the mouse button each time he wishes to increase or decrease the point number index.

Escape-Key: Exits the Re-distribute subroutine, and goes back to the Main Menu.

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